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The Production of Organic Matter and the Utilization of Solar Energy by a Forest Plantation of *Pinus nigra* var. *austriaca*

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With one figure in the text

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Synopsis

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The annual accumulation and the total production of organic matter since the planting of a plantation of *Pinus nigra* var. *austriaca* have been studied on a particularly suitable object, viz., the plantation on and besides a lysimeter of the P. W. N. at Bakkum. The original soil was clean dune sand and therefore also the accumulation of organic matter on and in the soil could be determined. Very exact data were available on what had been removed at thinnings.

The annual production of fine rootlets thinner than 5 mm was determined as 350 kg of carbon/ha.

The annual total accumulation of energy in standing trees and soil was, for the age-period from 19—22 years, determined as 58.3×10^6 kcal/ha. This corresponds with a utilization percentage of 0.65 % of the average annual total incoming solar energy of 90,000 cal/cm². Using the thesis that the fixed quantity of energy is proportional to the total needle mass we found a utilization percentage of 0.76 % for the same period.

Calculated over the whole growth period from 0—22 years the utilization percentage was 0.43 % of the incoming radiation.

Like Ovington we found that the utilization percentage of a forest corresponds with that of well growing agricultural crops (0.5—1.0 % according to Wassink).

An einer besonders geeigneten Stelle, auf und neben dem Großlysimeter der P. W. N. bei Bakkum, wurde die jährliche Akkumulation und Gesamtproduktion eines Bestandes von *Pinus nigra* var. *austriaca* seit der Anpflanzung bestimmt. Der ursprüngliche Boden war bloßer Dünensand und deshalb war es möglich, die Akkumulation von organischer Substanz auf und im Boden zu bestimmen. Sehr genaue Daten über die Durchreiserung standen zur Verfügung.

Die jährliche Produktion von Feinwurzeln, dünner als 5 mm, wurde mit 350 kg Kohlenstoff pro Hektar bestimmt.

Für die gesamte jährliche Energieakkumulation, im Baumbestand und im Boden, für das Bestandsalter von 19—22 Jahren, wurde ein Wert von $58{,}3 \times 106$ kcal/ha bestimmt. Dieser Befund stimmt mit einem Nutzungskoeffizienten von 0,65 % der durchschnittlichen jährlichen Einstrahlung von 90000 cal/cm² überein.

Ausgehend von der These, daß die gebundene Energiemenge der Gesamtnadelmasse proportional sei, fanden wir einen Nutzungskoeffizienten von 0,76 % für die gleiche Periode.

Umgerechnet auf die gesamte Wachstumsperiode, von der Anpflanzung bis zum 22. Jahr, betrug der Nutzungskoeffizient 0,43 % der Einstrahlung.

Wie Ovington, fanden auch wir, daß der Nutzungskoeffizient eines Waldes mit dem von Ackerkulturen gut übereinstimmt (nach Wassink 0,5—1,0 %).

1. Introduction

Foresters have been collecting data on wood-yield for a long time, to determine the wood production in a certain tree species under various site factors. They understand wood production in an economic sense, viz., the produced mass of marketable wood. Because the

market value of forestry products is lower, the financial returns per unit of surface in forestry are mostly considerably lower than those of arable land or pasture.

Another question is whether also in total production of organic matter, and in utilization of incoming solar energy forests are less valuable than arable land or pasture. In studies on this subject information on the marketable wood production is also wanted, but not sufficient. For the produced mass of branches, roots and leaves may be worthless in an economic sense, but it is an integral part of the total production of organic matter.

Various workers have tried to determine the total production of existing forests (reviewed by OLSON, 1964). The total organic mass of the above ground parts can be determined rather easily and with reasonable accuracy. However, measuring the root system requires a great deal of time and energy. This is the main reason why data on root systems are scarce. In the last few years OVINGTON has published on this subject.

Information on the total organic mass present in a living forest stand of a certain age is certainly important, but also the mass of material that in the course of the years has been shed, such as dead branches, leaves, fruits, etc. should be taken into account. The amount of organic matter that annually falls to the ground can only be determined by catching it in trays during a number of years. The laboriousness of such procedure is one reason why data on this subject are quite scarce (VAN DER DRIFT and WITKAMP, 1961; OVINGTON, 1958 and later.).

2. Material and methods

The plantation of *Pinus nigra, var. austriaca*, planted in 1941 on lysimeter no 4 of the Provincial Watercompany of North Holland (P. W. N.) looked particularly suitable for measuring its total production of organic matter. First, it is a plantation on clean dune sand with originally a negligible amount of organic matter. Second, its history was well documented because the exact weight of boles, branches and needles of trees that were removed at thinnings was known. For data on thinning we had access to the files of the P. W. N.-office at Bakkum.

The four lysimeters have been described by VAN NIEVELT (1952) and WIND (1958). Like the other three, no 4 has a surface of 25×25 m, and a content of about 1500 m^3.

We began sampling the plantation in the summer of 1961. Each bole after having been sawn into manageable lengths was weighed; at every 50 cm a disc of about 2 cm thick was sawn off; these discs were immediately weighed, then dried in the laboratory, and chopped to pieces; a sample was taken from the pieces from one tree and then finely ground in a Casella "Grain mill".

From the branches a representative sample was taken which we divided into dead branches (with needles and without needles) and living branches. In both categories the needles were removed and treated as two separate samples. The branches were dried and sawn to thin discs. A sample of these discs was chopped up and put through the grain mill. Finally all samples were pulverized in a vibrating ball-mill.

Pulling or digging out roots would have disturbed the lysimeter too much. Therefore the interrelation in weight between bole and root system was determined from trees in two plots lying besides the lysimeter. Those two plots in size, treatment, etc., agreed with the lysimeter plots, except in the data of the first thinning.

Determining the exact weight of a root system is far from simple. For obtaining optimal samples, first the total rootsystem should be minced. This was impossible and we therefore had to restrict ourselves to drying and processing a part of the thin and thick roots. Other difficulties were, that it is not easy to obtain representative samples of branches; that waterlosses by branches and needles are not the same; and that no windtight shelter for weighing was available. Weighing in the field was rather difficult, since not only samples of several tens of kilograms had to be weighed, but also samples of only a few grams.

Personnel of the P. W. N. had carefully registered the mass of boles and branches removed from the lysimeter plot during thinnings in 1954, 1959 and 1962. Dead trees removed at other times had been registered in the same way.

The thinning of 1962 comprised 99 trees; 7 of these were sampled and analysed, as well as 5 trees in total from the two plots beside the lysimeters.

Although the sampling, etc., was carried out with the greatest care, the calculations and approximations in our opinion cause such potential unreliability that expressing the results in whole percents is hardly justified. However, to avoid obscurity in the tables, the calculated percentages therein have not been rounded off.

In the pulverized samples carbon was determined by elementary analysis in a Coleman "carbon-hydrogen analyzer", nitrogen is some samples by the Kjeldahl method (BREMNER, 1960), but in the majority of samples in a Coleman "Nitrogen analyzer" (of N. I. O. Z., DEN HELDER).

The heat of combustion (table 1) was determined in a "Mikro-Bombe" calorimeter (made by PETERS, Berlin). As a rule there was very good agreement with figures found for *Pinus nigra* by OVINGTON (OVINGTON and HEITKAMP, 1960). However, for unaccountable reasons no reliable values could be found for the H- and A-layer of the lysimeter; the variation was too great, and the calorific values were improbably high if related to the available carbon.

Table 1 Heat of combustion of *Pinus nigra* var. *austriaca* in cal. per g. of dry matter

green needles	4868
dead needles	4914
boles	4785
living branches	4902
dead branches	4960
roots	4741
F-layer (lysimeter 4)	4546

Tables 2—5 summarize the measurements and determinations that could be made as a result of the thinnings. For calculating the volume of the boles the following methods were applied:

a) Of all trees on the lysimeter the height and the cross-section at 1.30 cm have been determined in various years. The product of height and area of cross-section at 130 cm is considered the volume of the bole.
b) Of the felled trees the content has also been determined after the lengths of 50 cm had been sawn, by length x average of the two terminal surfaces.
c) The content of the tree sections could be determined by submersion in a xylometer, i. e., a vessel filled to the overflow hole with water.
d) Of a number of trees in the plantation and in the thinnings the bole volume has been calculated from the height x halfway cross-section (table 5).

The results from the last three methods show little mutual difference.

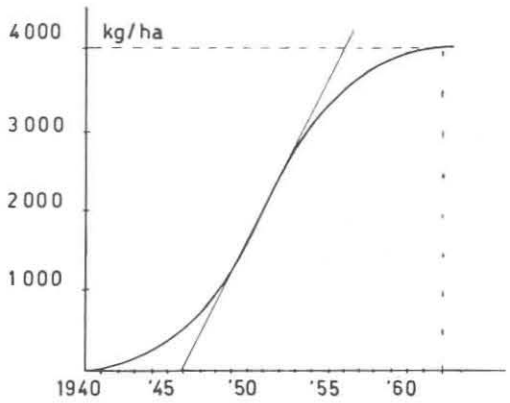

Fig. 1. Graphic extrapolation of needle production during the total period of development of the plantation. Calculations taken from the data of thinnings.

3. Calculations of the biomass

The biomass, the amount of organic matter in the living plantation, was calculated from the data in tables 2—5.

Early in 1962 before the thinning, according to table 2 (1st column) exactly 300 trees stood on the lysimeter; their content was (from $F_{130} \times$ height) calculated as 10.213 m³. At thinning 99 trees were felled with a content of 2.328 m³, while also one dead tree was removed. The average contents per tree of thinnings, and the average contents per tree in the remaining trees were therefore in the proportion as 1 : 1.7. Since the total weight

Table 2 Survey of the removed material at thinnings of Lysimeter IV and of the adjacent plots

	Lysimeter IV				Adjacent plot North			Idem East		
	Number of trees	Bole Volume Xylometer dm^3	Weight kg	Branches + needles weight kg	Number of trees	Bole Volume dm^3	Branches + needles weight kg	Number of trees	Bole Volume dm^3	Branches + needles weight kg
Before 1st thinning	536	—	—	—	616	—	—	602	—	—
Thinning December 1951	—	—	—	—	215	572	893	208	703	913
Thinning April 1954	140	528	569	396.4	—	—	—	—	—	—
Dead October 1957	—	—	—	—	19	184	—	21	284	—
Thinning March 1958	—	—	—	—	150	1714	875	130	1777	892
Dead May 1959	5	90	11.1	5	—	—	—	—	—	—
Dead November 1959	—	—	—	—	9	142	—	13	283	—
Thinning May 1959	88	1275	1160.7	736	—	—	—	—	—	—
Dead February 1960	—	—	—	—	3	60	—	4	150	—
Dead June 1960	—	—	—	—	4	99	—	4	105	—
Dead September 1960	3	20	21.2	10	8	241	—	1	42	—
Dead August 1961	—	—	—	—	5	137	—	1	26	—
Thinning April 1962	99	1656	1547.0	901	52	1709	691	50	1637	681
Standing May 1962	200	—	—	—	151	—	—	170	—	—

Table 3 Sample data of the stand on Lysimeter IV (1962)

Tree number		28	38	49	56	95	242	406	Average
BOLE									
Volume calculated from H · F_{130}	dm^3	44.17	29.51	9.88		34.03	40.38	63.03	40,03
Volume in Xylometer	dm^3	31.11	19.65	6.91	—	24.26	28.05	42.98	25.49
Fresh weight	kg	28.92	17.92	6.63	—	22.70	27.44	41.00	24.10
Dry weight	kg	13.88	6.72	2.53	—	9.50	11.66	17.60	10.31
Carbon	%	*47.88*	*49.02*	*48.02*	—	*48.20*	*49.36*	*48.87*	*48.60*
Carbon weight	kg	6.65	3.29	1.21	—	4.58	5.76	8.60	5.01
Nitrogen	%	*0.23*	*0.16*	*0.26*	—	*0.15*	*0.18*	*0.25*	*0.21*
Nitrogen weight	kg	0.032	0.011	0.007	—	0.014	0.021	0.044	0.026
C/N		**208**	**299**	**175**	—	**327**	**274**	**195**	**233**
BRANCHES + NEEDLES									
Branches + needles, Fresh weight	kg	14.22	10.60	—	14.77	15.88	—	—	13.90
Branches + needles, Dry weight	kg	8.52	6.44	—	8.15	7.89	—	—	7.75
Branches, calculated dry weight	kg	6.11	5.25	—	6.06	6.10	—	—	5.72
Carbon	%	*48.7*	*48.3*	—	*48.75*	*49.75*	—	—	*48.9*
Carbon weight	kg	2.97	2.54	—	2.95	3.08	—	—	2.88
Nitrogen	%	*0.38*	*0.36*	—	*0.49*	*0.58*	—	—	*0.43*
Nitrogen weight	kg	0.024	0.019	—	0.029	0.037	—	—	0.027
C/N		**122**	**134**	—	**100**	**84**	—	—	**108**
Needles, dry weight	kg	2.41	1.19	—	2.29	2.35	—	—	2.06
Carbon	%	*47.09*	*47.68*	—	*49.0*	*48.57*	—	—	*48.13*
Carbon weight	kg	1.13	0.57	—	1.12	1.13	—	—	0.99
Nitrogen	%	*0.05*	*1.04*	—	*0.80*	*1.09*	—	—	*1.0*
Nitrogen weight	kg	0.025	0.012	—	0.018	0.025	—	—	0.020
C/N		**45**	**48**	—	**62**	**45**	—	—	**50**

Table 4 Sample data on stands of plots adjacent to Lysimeter IV (1963)

	Tree	A	B	C	D	E	Average
BOLES							
Fresh weight	kg	36.20	50.85	24.37	62.38	28.90	40.54
Dry weight	kg	13.00	17.96	9.39	23.01	11.04	14.88
Carbon	%	*48.78*	*48.22*	*48.08*	*48.00*	*48.24*	*48.26*
Carbon weight	kg	6.36	8.67	4.53	11.05	4.78	7.08
Nitrogen	%	*0.28*	*0.23*	*0.21*	*0.23*	*0.24*	*0.238*
Nitrogen weight	kg	0.036	0.041	0.020	0.053	0.026	0.035
C/N		**176**	**212**	**226**	**208**	**205**	**206**
ROOTS							
Fresh weight	kg	10.0	18.3	11.3	24.0	9.5	14.6
Dry weight	kg	4.27	5.29	3.74	8.13	3.44	4.98
Carbon	%	*47.47*	*47.08*	*50.49*	*47.93*	*48.17*	*48.22*
Carbon weight	kg	2.03	2.85	1.88	3.78	1.60	2.43
Nitrogen	%	*0.29*	*0.47*	*0.36*	*0.43*	*0.32*	*0.37*
Nitrogen weight	kg	0.012	0.028	0.013	0.034	0.011	0.020
C/N		**163**	**102**	**140**	**111**	**150**	**124**
BRANCHES							
Living branches + needles							
Fresh weight branches + needles	kg	6.38	9.50	6.60	17.83	10.65	10.20
Dry weight branches + needles	kg	1.23	1.63	1.08	3.33	2.14	1.88
Carbon	%	*49.80*	*48.89*	*48.51*	*49.47*	*47.84*	*48.90*
Carbon weight	kg	0.61	0.82	0.51	1.66	1.00	0.92
Nitrogen	%	*0.53*	*0.41*	*0.50*	*0.73*	*0.49*	*0.53*
Nitrogen weight	kg	0.007	0.007	0.005	0.024	0.010	0.0106
C/N		**87**	**117**	**102**	**69**	**100**	**95**
Needles dry weight	kg	1.63	2.53	2.05	4,84	2.73	2.75
Carbon	%	*48.79*	*48.39*	*47.09*	*48.10*	*48.43*	*48.16*
Carbon weight	kg	0.79	1.22	0.98	2.32	1.35	1.33
Nitrogen	%	*1.40*	*1.28*	*1.22*	*1.13*	*1.06*	*1.22*
Nitrogen weight	kg	0.023	0.032	0.025	0.055	0.030	0.033
C/N		**34**	**39**	**39**	**42**	**45**	**40**
Dead branches							
Fresh weight dead branches	kg	9.08	6.32	5.81	5.00	3.50	5.94
Dry weight dead branches	kg	6.81	5.02	4.21	3.26	2.51	4.36
Carbon	%	*49.03*	*50.04*	*49.81*	*49.59*	*50.38*	*49.89*
Carbon weight	kg	3.36	2.51	2.09	1.62	1.27	2.17
Nitrogen	%	*0.62*	*0.55*	*0.67*	*0.58*	*0.53*	*0.59*
Nitrogen weight	kge	0.042	0.028	0.028	0.019	0.013	0.26
C/N		**79**	**90**	**75**	**85**	**98**	**85**

of the felled trees was 1547 kg, the weight of the remaining stand (of 200 trees) was $1547 \times 1.7 \times 200 = 5260$ kg fresh weight. A dry matter content of 42 % gives, for the complete plantation before thinning, a dry weight of $(5260 + 1547) \times 0{,}42 = 2860$ kg of bole wood. This corresponds with a combustion heat of 13.68×10^6 kcal.

The root-weight was 0.36 of the bole weight (according to table 4). Therefore the lysimeter contained 1030 kg dry weight of roots, with a combustion heat of 4.89×10^6 kcal.

Table 5 Survey of data on standing trees and thinnings on Lysimeter IV (5th April 1962)

	Number	Average height (H)	Average gross-section halfway height	Average Volume according to:			Average weight without branches
				Height x area cross-section at $^1/_2$ H	Section-method	Xylometer in dm³	
		in m	in cm	in dm³	in dm³	in dm³	in kg
Standing trees	20	6.17	6.47	22.5	22.5	—	—
Thinnings	20	6.07	5.43	14.2	15.2	16.8	14.7
Total Thinnings, 99 trees, comprises:				1478.9 (2328.0)*)		1655.8	1547.0 (2447.6)**)

*) = F 130 = area of cross section at 130 cm height x total height of tree.
**) = Weight of branches + needles.

Per m³ of bole volume a fresh weight of needles and branches of 386 kg was found in the thinnings (in those of 1959 a weight of 400 kg was found). The total bole content of the plantation before thinning was 10.21m³ and therefore the fresh weight of the branches + needles 3965 kg. The dry weight, at a dry matter content of 58.8 %, was 2332 kg, of which 25.4 %, or 592 kg, related to the needles.

The following table summarizes the actual dry weight, and the various data per hectare.

Biomass of the 22 years (1940—1962) old plantation of *Pinus nigra* var. *austriaca*.

	Dry weight kg/lysim.	kg/ha	Carbon kg/ha	Nitrogen kg/ha	Total energy 10^6 kcal/ha
Boles	2,860	45,500	22,210	113.7	217.8
Branches	1,740	27,660	13,550	119.0	135.9
Needles	592	9,400	4,520	94.0	45.3
Roots	1,030	16,380	7,900	60.3	77.8
Total	6,222	98,940	48,180	387,0	476,8

Σ = 4.768 kcal/cm²

4. Total production of organic matter

We now have to consider the question how much organic matter the plantation has produced during the 22 years of its existence (gross production, MACFADYEN, 1957; net primary production, OVINGTON, 1962).

The data on thinning and removal of dead trees (table 2) show that the following amount of organic matter has been removed from the plantation, expressed per hectare.

Quantities removed from the plantation

	Dry matter/ha kg	Carbon/ha kg	Nitrogen/ha kg	Total energy/ha 10^6 kcal
Boles	9,640	4,660	23.4	46.0
Branches	7,420	3,630	26.6	36.5
Needles	2,910	1,400	35.5	13.75
Roots	3,440	1,670	12.7	16.4
	23,410	11,360	98.2	112.65

Although at thinning no roots were removed, we have incorporated them in the table, for otherwise this mass would not be included in our calculations.

We also have to estimate the quantity of branches and needles shed in 22 years, and the annual production of fine rootlets. In view of the age of the plantation, and the manner of removal of the branches at thinnings, we have left the natural shedding of branches out of consideration. Therefore it is only the shedding of needles that matters. This takes place all the year round in a lesser or greater degree. TINBERGEN (quarterly report ITBON, 1949) thinks it likely that in a growing forest of *Pinus sylvestris* the annual amount of needles shed agrees with the annual mass of needles developed. He distinguished the total number of needles present in winter on the tree into: first years 45 %, second year's 45 %, third year's 10 %. DOOM and VAN DEN HAM (Internal report ITBON) compared the summer weights of the 3 classes and found that they varied with the quality of the stand. First year's needles in a first rate stand weighed 26.8 % of the weight of all needles, while in a second rate stand the percentage varied from 32.6—39.1 %. In summer, therefore, about $^1/_3$ of the total needle weight consists of young needles, in winter about 40—45 %.

We have assumed that these values for *Pinus silvestris* also hold for *P. nigra var. austriaca*. Then the annual production of needles at age 22 years, in 1962, was 40—45 % of the total needle mass of 9400 kg dry/weight/ha, which means 3760—4230 kg/ha per annum with a combustion heat of about 19×10^6 kcal. The data from the 1959 thinnings give a similar figure, viz. $\pm$ 4000 kg/ha. Apparently the needle production in 1959 had reached a fairly constant level of about 4000 kg/ha. The first thinning (1954) on the lysimeter gave exceptionally low figures for branches and needles. Therefore we did not use those, but instead used the thinning data of 1951 for the plots besides the lysimeter. In 1951 the annual production of needles was calculated as being 1936 kg/ha, this time by using a conversion factor of 40 instead of 45 %, because on young trees the percentage of third year's needles is higher.

From the estimates of 1951, 1959 and 1962 we constructed a graphical representation of the annual needle production. From this graph (fig. 1) we calculated the total needle production since the time of planting. This was found to be 43,000 kg of dry matter from 1941 till April 1963. For the total production of litter we must diminish the latter figure by the weight of the needle mass present on the trees after the last thinning, viz., 9400 kg/ha. The final sum becomes 33,600 kg/ha which corresponds with 16,100 kg/ha of carbon, 346 kg/ha of nitrogen and 163×10^6 kcal/ha.

The production of fine rootlets could only roughly be estimated. Both KALELA and HEIKURAINEN of Finland have studied the periodicity in growth of thin roots (thinner than 5 mm) of *Pinus silvestris* and *Picea abies* in the H- and A-layers. KALELA demonstrated the occurrence of a pronounced annual maximum in total length of roots. The following table, relating to a stand of *Pinus silvestris* (75 years old, 1020 trees hectare, bole volume 194 m³, height 16 m, diameter 15.4 cm), was taken from his 1955 paper.

Total length of thin roots in meters per m² of forest surface on various dates (Kalela, 1955)

	15/5	30/5	15/6	30/6	15/7	30/7	15/8	30/8	15/9	30/9	15/10
H-layer	261	290	278	367	499	536	403	319	283	267	251
A-layer 0— 20 cm	316	385	468	491	511	491	423	357	373	380	346
A-layer 20—50 cm	39	67	94	89	85	89	76	58	57	53	50

This shows that about half the roots present in the humus layer in summer have disappeared when winter begins. This, combined with other data, suggests an average life span of only one year for roots thinner than 1 mm. Also HATCH (1937) has stated: "Small roots of pine normally live but one year".

HEIKURAINEN (1955) who studied roots in peat soil (in which the difference between H- and A-layer is obsolete) found different fluctuations in root length for roots of different thickness. In roots of less than 1 mm thick the autumn length was 66 % of the summer length, in roots of 1—2 mm 78 %, of 2—5 mm 91 % and in roots of more than 5 mm 100 %.

KALELA showed that total root length is correlated with the age of the stand, and that it reaches a limit for roots thinner than 5 mm, in *Pinus silvestris* after about 60 years. His data show that both root length and root volume per m² at age 20 years are about twice those at age 10 years. The increase in length from age 20 to 30 years is smaller than from age 10—20 years.

We did not carry out such detailed investigations, but in the summer of 1964 we searched twenty squares of 25 × 25 cm for roots. After conversion to grams per m² and to dry weight the following data resulted:

L-, F-layer	:	0.0 g/m²
H-layer	:	11.0 g/m²
A_1 (0—2.7 cm)	:	135.0 g/m²
Total	:	146,0 g/m²

From this root mass a sample was sectioned by microtome for determining the age. The proportion of dead rootlets was high, and this suggested that their average life span is very short.

If we assume that, as in Finland, in the no 4 lysimeter one-half of the summer value of the rootlets disappears every year, and is converted to humus, then the total root increase for 1964 was $^1/_2 \times 146$ g/m², or 730 kg/ha. KALELA's data on the interrelation between root length at age 10 years, and that at age 20 years, seem to permit the assumption that in the life span of 20 years, 7300 kg/ha of dry matter in roots has been produced. The combustion heat of this is 34.6×10^6 kcal/ha.

Therefore the total accumulation of energy in our lysimeter during 20[1]) years (April 1962) was:

	Dry matter kg/ha	Combustion heat 10^6 kcal/ha
Standing trees	98,940	476.8
Thinnings	23,410	112.6
Fallen needles	33,600	163.0
Fine roots	7,300	34.6
Total	163,250	787.2

The sum of 787.2×10^6 kcal/ha is the "gross production" or "net primary production". It corresponds with 8.75 % of the average annual amount of incoming solar energy of 90,000 cal/cm². Averaging over the twenty years of the plantation shows that per annum only 8.75 : 20 = 0.43 % of the total of the incoming solar energy was utilized.

We think it most obvious to express the utilization percentage in total incoming solar radiation, for also heat radiation plays a rôle in the physiological condition of the plant during photosynthesis.

5. The production of organic matter in the age period 19—22 years of the plantation

If we assume that the annual production of organic matter approached a limit in the period from 1959—1962, then the annual production during this period could be used as

1) The production in the first two years has been left out of consideration as there was hardly any needle production. The transplanting caused losses that were repaired. Growth was poor.

an estimate for the average annual production of a normal growing *Pinus nigra* var. *austriaca* plantation between the initial growing-up phase, and the phase of reduced growth at old age.

The total production and the accumulated energy in this period of three years can be calculated from the data on thinning in table 2, on the fresh and dry weights in tables 3 and 4, and on the combustion energies in table 1.

In 1959 no 4 lysimeter carried 391 trees, with a total bole-volume of 9.836 m³ (calculated from height $\times F_{130}$). The thinnings of that year consisted of 88 trees with a volume of 1.892 m³ and a weight of 1160.7 kg. The weight of branches and needles was 736 kg. The weight of the boles before thinning can therefore be calculated as being $\frac{9.836}{1.892} \times 1160.7 = 6050$ kg. The dry weight of this was 42.6 % or 2577 kg, which amounted to 41,200 kg/ha. The fresh weight of branches and needles was $\frac{9.836}{1.892} \times 736 = 3820$ kg, the dry weight of which was 58.8 % or 2240 kg which amounted to 35,850 kg/ha. 25.5 % of the latter weight related to needles, i. e., 9160 kg/ha of dry needles.

After thinning, the bole-volume was reduced to 70,943 m³, or in mass per ha: 33,200 kg dry matter in bole-wood, 21,600 kg in branches and 7350 in needles. The root-weight was calculated from the bole-wood, with a factor 0.36. Therefore before thinning the dry weight of living roots would have been $0.36 \times 41{,}200 = 14{,}800$ kg/ha, and after thinning 11,900 kg. In May 1959, after thinning there would have been present:

	Dry matter kg/ha	Combustion heat 10^6 Kcal/ha
Boles	33,200	158.5
Branches	21,600	106.2
Needles	7,350	35.8
Roots	11,900	56.4
Total	74,050	356.9

As we saw above the plantation in 1962 before thinning had a calculated combustion heat of, in total, 476.8×10^6 kcal/ha. The production of thin rootlets that as dead organic matter was added to litter and soil, was 730 kg of dry matter/ha, or 3.46×10^6 kcal/ha. The litter production in the 3 years period from 1959—1962 consisted in the first place of the mass of needles that after the thinning of 1959 were still on the trees. This quantity was complemented by about half the needles developed in the year after thinning, and a small amount of prematurly fallen needles from later years. This complement was estimated as 60 % of annual production, which means 1760 kg/ha. In 1959 in total 7350 kg/ha of needles were present and therefore the litter production must have been $1760 + 7350 = 9110$ kg/ha or 44.8×10^6 kcal/ha. In 1959—1962, therefore, the total amount of energy accumulated was: 476.8 (in 1962) − 356.9 (in 1959) + 44.8 (fallen needles) + 10.4 (3 times dead rootlets) = 175.1×10^6 kcal/ha. On the basis of an average annual incoming solar energy of 90,000 cal/cm² this amounts to a utilization of 0,65 %.

The utilization percentage can also be estimated by assuming that the accumulated amount of energy is in direct proportion to the quantity of chlorophyl or of leaf-mass (Bray, 1962). The needle-mass consisted of the needles produced during the period but already shed (1760 kg/ha) and the needles that at the thinning of 1962 still were on the trees (9400 kg/ha), in total 11,160 kg/ha. From fig. 1 one can deduce that the needle production since that planting of the plantation has been about 43,000 kg/ha, and that the

total amount of energy accumulated by the plantation (stand, thinnings, litter, soil) = 787×10^6 kcal/ha. Consequently during the period from 1959—1962 $\frac{11.160}{43.000} \times 787 \times 10^6$ kcal ha = 204.5×10^6 kcal/ha would have been accumulated. This amounts to a utilization percentage of 0.76.

6. Conclusion and discussion

The conversion-factors used in this paper are doubtless disputable since they are based on only a few data. But, as far as we could find out, no better ones were available. This paper is merely a first step towards a better insight into the total production of organic matter by a forest, in addition to work in this field that has already been done by Ovington c. s. The utilization percentages of the total amount of incoming solar energy by a plantation of *Pinus nigra var. austriaca* that we found show rather different values depending on the period to which the calculations relate, or on the way of calculating. Basing the valuation on the total growth between the 19th and 22nd year gave a utilization of 0.65%. But if it is based on the needle mass produced in the same period which for this purpose has been considered proportional to the mass of chlorophyl, we found a utilization of 0.76%. If the calculation is carried out on the production of organic matter during the total growth period of the plantation, then we found a utilization percentage of only 0.43%. However, if one considers that in the latter calculation the development of the trees from their youth is involved, this low percentage is certainly acceptable in comparison the other two that we mentioned.

Also for agricultural crops the utilization percentage varies strongly (Wassink, 1948). Sugarbeets, mangolds, maize and sugarcane utilize 1—1.1% of the total incoming solar energy, but potatoes, turnips, winterwheat and *Lolium westerwoldicum* about 0.6%, and onions even as little as 0.23%.

Ovington (1962) found very high values for *Pinus silvestris* in England, viz., 1.3%. Bray (1962), however, estimates the utilization of a small oak wood in Minnesota at only about 0.26%.

From the data obtained we venture to conclude that there is not much difference in utilization percentage of incoming solar energy between trees and agricultural crops. It certainly is evident that as to trees, with their long rotation period, a careful choice of species or variety to be planted is of great importance, for a high utilization percentage may possibly mean more bole wood, and certainly more organic matter that is brought into the organic matter cyclus, to the advantage of the ecosystem of the soil.

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